SURFACE PRESSURE VARIATIONS AT COASTAL STATIONS DURING THE PERIOD OF IRREGULAR MOTION OF HURRICANE CARLA OF 1961

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ABSTRACT

Surface pressure observations at stations along the Texas coast during the approach of hurricane Carla of 1961 have been examined in an attempt to determine the extent to which the storm as a whole participated in the irregular motion indicated by the track of the storm center as followed by radar. The pressure variations at coastal stations were found, in general, to correlate rather poorly with changes in the direction and speed of motion of the storm center. The best agreement was shown by the Galveston observations which were made some 100–150 mi. to the right of the storm track.

1. INTRODUCTION

As hurricane Carla approached the Texas coast on September 10 and 11, 1961, the storm center, as tracked by radar, showed very marked changes in its direction and speed of motion over rather short periods of time (fig. 1). This irregular movement is well documented by observations from three or more radars and it is shown in a very striking manner when the WSR-57 radar film from Brownsville is viewed as a time lapse movie.

Oscillatory tracks of tropical cyclones have been reported by several investigators, as summarized by Jordan [1], but it is unlikely that any storm prior to Carla is as well documented or, because of the storm location, caused greater concern for the hurricane forecaster. The observed oscillations were roughly of the form suggested by the theoretical work of Yeh [2] but the amplitude and period of the oscillations in Carla were considerably smaller than the examples presented by Yeh.

Tropical cyclones are usually tracked by successive "fixes" of the eye position and it is normally assumed that the storm as a whole moves in the same direction and at the same speed as its center, as identified with the geometrical center of eye. In this note, surface pressure variations at coastal stations are used in an attempt to determine the extent to which hurricane Carla as reflected in the large-scale pressure distribution participated in the oscillatory motion shown in figure 1.

2. SURFACE PRESSURE VARIATIONS AT COASTAL STATIONS

Carla was an unusually large hurricane and its influence was felt along the complete Texas coast before and during the time it moved inland near Port O'Conner. All of the coast except for a short segment near Brownsville experienced gusts of at least hurricane force and the pressure fall was everywhere in excess of 15 mb. The pressure gradient along the Texas coast was greater than 4 mb. per latitude degree during most of the period that the storm was in the oscillatory portion of the track (fig. 1). Since the amplitude of the oscillations in the storm track was as great as 20–25 mi., this would suggest that pressure changes at the

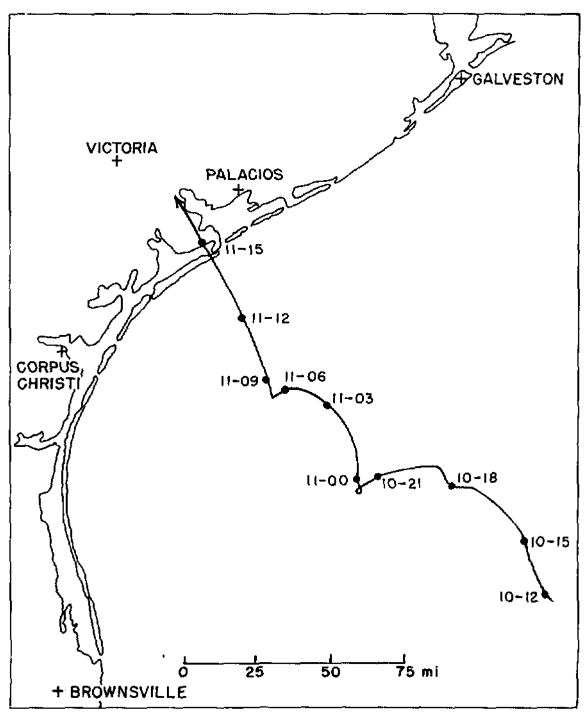

FIGURE 1.—The track of hurricane Carla on September 10–11, 1961 as determined from the Brownsville WSR-57 radar "fixes" (adapted from a figure given by Senn, Hiser, and Stevens [4]).

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individual stations should have been of sufficient magnitude to be detected if, in fact, the whole storm, as identified with the pressure field, moved in the same manner as its center.

Barograph traces from the stations shown in figure 1 have been used in studying the pressure variations during the period of irregular motion of hurricane Carla. Since the microbarographs at these stations were set to make a full revolution in 12 hr., it was possible to read off pressure values at frequent intervals. Ten-minute readings were made and these were then smoothed by taking 30-min. overlapping averages. The smoothed values were plotted against time and are reproduced as the solid curves in figures 2–6. The distance of the storm center from the individual stations, as determined from the track shown in figure 1, is given by the dashed curves in these figures.

In looking at figures 2–6, we shall attempt to assess the extent to which the pressure variations at the individual stations can be related to the movement of the large-scale, steady-state pressure distribution of the hurricane. Later, some comments will be made in respect to the possible influence of smaller-scale, non-steady features of the surface pressure field.

The pressure changes at Palacios during hurricane Carla were much greater that at the other coastal stations shown in figure 1 with a minimum pressure below 960 mb. (fig. 2). The curves in figure 2 show, in a very general way, that the pressure fell as the storm approached

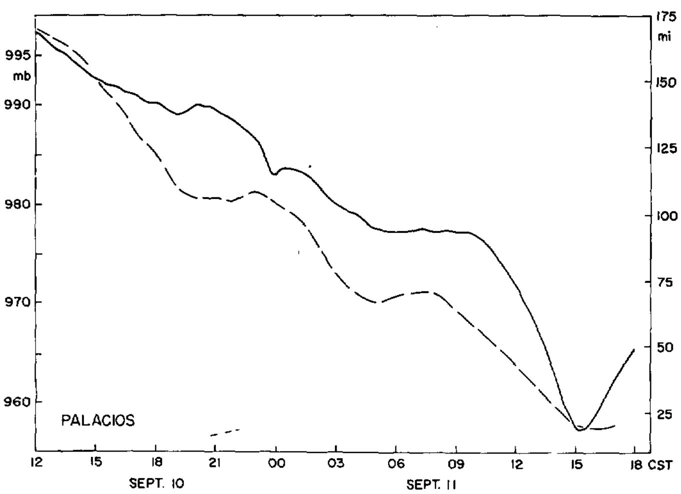

FIGURE 2.—A time plot of the surface pressure at Palacios, Tex. (solid curve) obtained by smoothing of data read from the microbarograph trace. The distance from the station to the hurricane center, as taken from the track in figure 1, is given by the dashed curve.

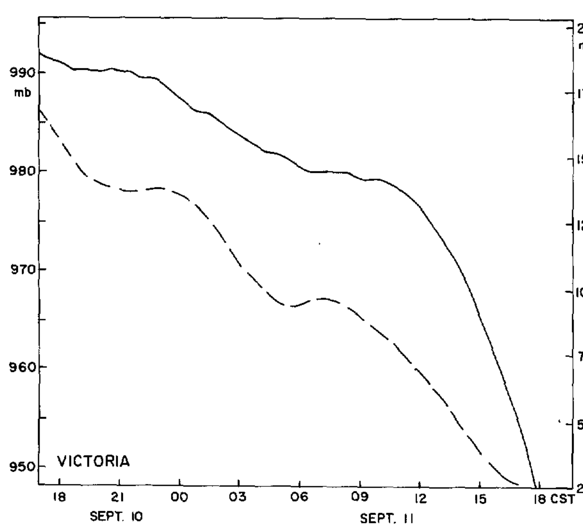

FIGURE 3.—Same as figure 2 except for Victoria, Tex.

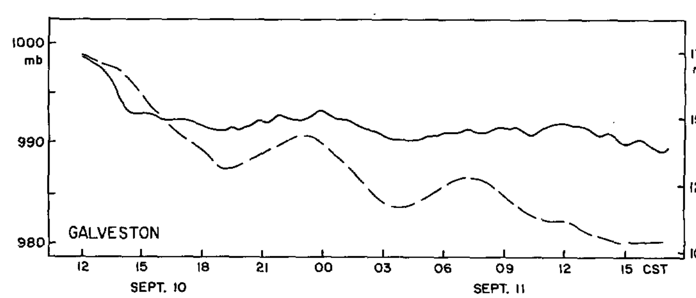

FIGURE 4.—Same as figure 2 except for Galveston, Tex.

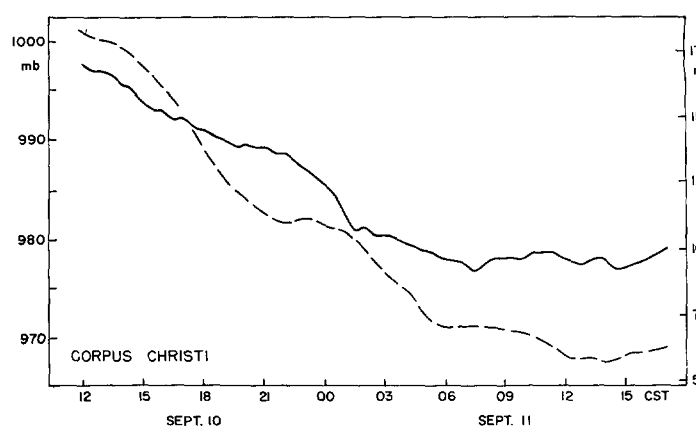

FIGURE 5.—Same as figure 2 except for Corpus Christi, Tex.

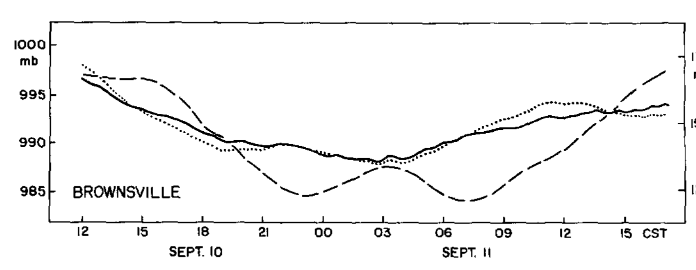

FIGURE 6.—The solid and dashed curves are the same as in figure 2 except for Brownsville, Tex. The dotted curve shows the surface pressure as adjusted for the mean diurnal pressure oscillation.

the station. However, during the period around 2200 CST on September 10, the pressure was falling fairly rapidly even though the storm center was momentarily moving away from the station. It is also of interest that the pressure was fairly steady during the period 0800–1000 CST on September 11 as the center was definitely moving toward the station. The curves for Victoria (fig. 3) show essentially the same features as those for Palacios but shorter-period pressure variations were much less prominent.

The pressure variations at Galveston (fig. 4) appear to be fairly closely related to the distance from the storm center, especially if the shorter-period oscillations were removed. The correlation tends to break down, however, during the period from 0800 to 1100 CST on September 11 as the storm started moving toward the coast on a rather smooth path. Thus, from the viewpoint of forecasting the landfall of the storm, the Galveston pressure data would have been virtually worthless.

Corpus Christi was somewhat closer to the storm center than Galveston during the irregular motion of the storm center but the correlation between pressure change and distance from the storm center (fig. 5) was quite poor during several periods. The pressure fall at Brownsville (fig. 6) was fairly regular but the pressure minimum occurred near 0300 CST on September 11 when the storm was at a somewhat greater distance from the station than it was a few hours earlier and also later.

The above attempt to associate the pressure variations at individual stations with the distance from the storm center was not very successful, and only at one of the five stations was there much indication that the large-scale pressure field of Carla moved in the same manner as the storm center during the period of irregular motion.

3. OTHER FACTORS INFLUENCING PRESSURE VARIATIONS AT INDIVIDUAL STATIONS

The pressure changes at the individual stations could, of course, be expected to be influenced by factors other than the translation of the large-scale features of the pressure distribution associated with the hurricane. These factors include changes in the intensity of the hurricane, the normal diurnal pressure oscillation, and small-scale disturbances within the hurricane circulation.

The central pressure in hurricane Carla was nearly constant during the period of irregular motion. The individual reports over the period from 1300 CST on September 10 to 1200 CST on September 11 varied between 942 and 936 mb. with no definite trend shown during the period. Much of this variability can probably be attributed to observational error in the dropsonde observations. Even if the central pressure were varying by several millibars over a few hours, relatively little of this change could be expected to be reflected at the coastal stations which were more than 100 mi. from the center during much of the period of interest.

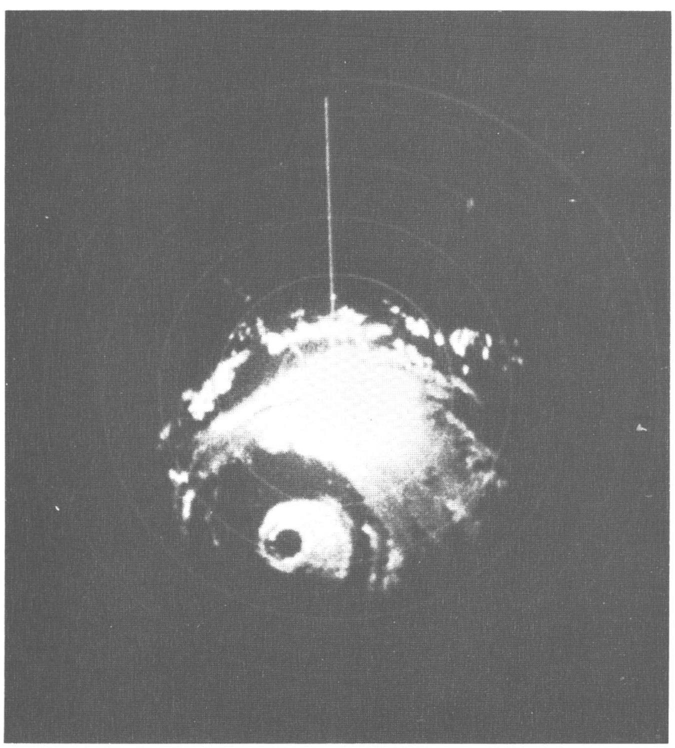

FIGURE 7.—A photograph of the WSR-57 radarscope at Galveston, Tex. taken about midnight on September 10, 1961. The center of the central ring echo was on a bearing of approximately 165 deg. and at a range of 145 mi.

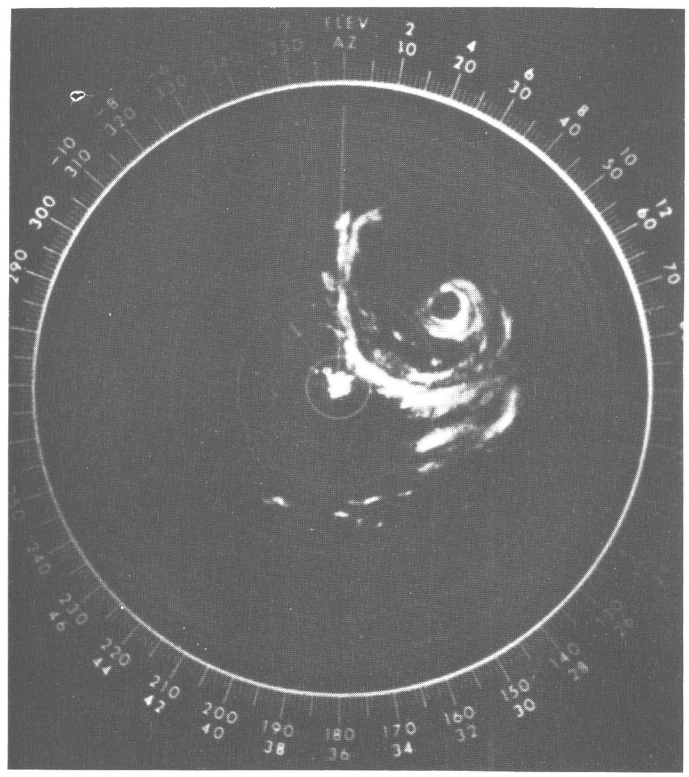

FIGURE 8.—A photograph of the WSR-57 radarscope at Brownsville, Tex. taken about 0100 CST on September 11, 1961. The center of the central ring echo was on a bearing of approximately 52 deg. and at a range of 130 mi.

It can also be shown that the normal diurnal variations were not great enough to influence the curves in figures 2–6 to any appreciable extent. Corrections for the normal diurnal variation were made, as shown for Brownsville by the dotted curve in figure 6. Even at Brownsville, where the pressure changes were much smaller than at the other stations, the normal diurnal change is relatively unimportant. Since the corrected curves led to no improvement in the correlation between the surface pressure variations and motion of the storm center, these have not been reproduced in figures 2–5.

There are pressure variations in hurricanes which are associated with the spiral radar bands and with smaller convective elements, although little is known about the relative importance of such features. If the variations due to such features were all of short duration, they could be eliminated by smoothing the pressure curves in figures 2–6. It is well-known, however, that the characteristic convective patterns in hurricanes may retain the same orientation from hour to hour, and even from one day to the next [3]. There is some suggestion that the marked pressure minimum observed just before midnight on September 10 at Palacios (fig. 2) may have been associated with a spiral band since a very similar minimum was observed at Corpus Christi some 2 hr. later (fig. 5). It is interesting that this feature was not shown at Victoria (fig. 3).

There are other types of asymmetries in the surface pressure distribution which could be important in accounting for the relatively poor correlation between pressure change and distance from the storm center noted in figures 2–6. A trough in the storm periphery might account for the fact that the lowest pressure at Brownsville was not observed at the time that the storm center was closest to the station. Although asymmetries in the pressure field of hurricanes are capable of introducing changes at an individual station, which would make it difficult to assess the large-scale influence of the movement of the hurricane in the pressure field, there is no evidence that the poor correlations shown by figures 2–6 are actually due to such factors. On the other hand, it is possible to view the oscillations in the storm track, as shown in figure 1, as asymmetries near the storm center which are not related to the large-scale pressure distribution or to the motion of the storm as a whole. The motion of the "whole" storm could perhaps be best defined by the track of the centroid of some arbitrarily chosen isotach, perhaps 48 or 64 kt. corresponding to full gale or hurricane force, but observations are ordinarily inadequate for any such definition of the storm center.

4. OTHER ASPECTS OF THE IRREGULAR FEATURES IN HURRICANE TRACKS

Radar observations in tropical cyclones have shown that in many cases the eye of the storm is defined by a ring-like radar echo which is somewhat isolated from the spiral bands of the storm. Hurricane Carla appeared to have a structure of this type late on September 10 as shown by the Galveston and Brownsville radars (figs. 7 and 8). Cases of this type have led to occasional reports of "double eyes" in tropical cyclones. The storm center would undoubtedly have been identified with the geometric center of the "inner eye." The fact that this inner ring is not always at the geometric center of the "larger eye" suggests that deviations from a smooth track such as shown in figure 1 could result from a circular motion of the central echo around the geometrical center of the "larger eye" as the whole storm is moving. An attempt was made to determine the extent to which the irregular features in the track of hurricane Carla could be accounted for by motion of this type. The fact that neither the Galveston nor Brownsville radar was able to detect the complete outer wall cloud, coupled with the difficulty that the time indicator could not be read from the radar films during most periods, complicated the analysis of the films.

The possibility that oscillations in the track of hurricane Carla shown in figure 1 were limited to the core of the storm is interesting, especially in view of the fact that pressure changes at most coastal stations did not appear to be correlated to any appreciable extent with variations in the speed and direction of motion of the storm center. Additional research is planned in which an attempt will be made to carefully composite data for hurricane Carla from all available radar stations. It is hoped that such data will prove adequate to determine the track of the geometrical center of the "larger eye" shown in figures 7 and 8. This could then be compared with the track of the "inner eye" as shown in figure 1.

Somewhat apart from the question of whether the oscillations in figure 1 were only of the inner core of the storm or of the whole storm circulation is the matter of the cause of such irregular features in the track of hurricanes. Sea surface temperature data in the western Gulf of Mexico prior to hurricane Carla were completely inadequate to establish whether there were thermal patterns in the ocean which might have contributed toward the irregular motion. It seems more likely that the irregular storm track was due to instabilities in the storm circulation but adequate models or observations do not exist to approach this problem from a theoretical point of view. The possible influence of the thermal fields should not be ignored, especially since with air-borne radiometers it should be possible to map the sea surface temperature field in some detail immediately in advance of tropical cyclones. If it could be documented that oscillations of the type shown in figure 1 occur over areas with weak sea surface temperature gradients, this should be helpful in directing attention toward the dynamical aspects of the structure and motion of the central portion of the tropical cyclone.

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